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Effects of Heat-Treatments on Tensile Strength and Electrical Conductivity of Locally Formulated Al-Ni Alloys

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Abstract:*This Paper investigated effects of annealing and age hardening on the ultimate tensile strength (UTS) and electrical conductivity of aluminium-nickel cast using sand mould. Pure aluminium melt was alloyed with nickel, which was added in 2% to 10% step 2. Annealing and age hardenings were carried out and obtained results showed that Al-2%Ni alloy has the highest UTS of 604.44MPa. On the other hand, Al-6%Ni Annealed alloy has the highest electrical conductivity, with a value of 6.15 × 10^7 S/m. The Al-4%Ni alloy combined both high strength and conductivity, having UTS of 603.28MPa and electrical conductivity of 5.69 × 10^7 S/m.*

Keywords: Heat-Treatment, Strength, Conductivity and Sand-mould

INTRODUCTION

Aluminium has varied fields of application including aerospace, vehicular, electrical, building and packaging purposes.Pure aluminium has weak and disadvantageous strength which can only be improved by alloying while its other mechanical properties are not tampered with. (Aniyi&Bello-Ochende, 1996 and Abifarin&Adeyemi, 2003). Aluminium is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from Aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. Pure aluminium has a low tensile strength, but when combined with thermo-mechanical processing, aluminium alloys display a marked improvement in mechanical properties, especially when tempered. Aluminium alloys form vital components of aircraft and rockets as a result of their high strength-to-weight ratio. Aluminium readily forms alloys with many elements such as copper, zinc, magnesium, manganese, and silicon (e.g., duralumin). Today, almost all bulk metal materials that are referred to loosely as "aluminium", are actually alloys. For example, the common aluminium foils and beverage cans are alloys of 92% to 99% aluminium (Pio, Sulaimin and Mamouda, 2005).

$$\sigma = \frac{1}{\rho}. \qquad 1$$

Where:

$$\rho = \frac{AR}{L} = \frac{VA}{IL}\ (\Omega\text{-m});\ \text{such that}$$

$$\sigma = \frac{1}{\rho} = \frac{L}{AR} = \frac{IL}{VA} \qquad 2$$

σ is in 1/Ω-m (Siemens, S)
(Reliy*et al*, 2010).

MATERIALS AND METHOD

The materials used for the experiments are; Aluminium metal, Nickel metal, hacksaw, melting furnace, ladle, sand mould, lathe machine, shaping machine, file, emery cloth, abrasive paper, polishing machine, etching reagent (Hydrofluoric acid, Hydrochloric acid, Nitric acid and water), metallurgical microscope, tensile testing machine, Whetstone bridge apparatus. The developed alloys were used in carrying out electrical conductivity test, tensile test, hardness test and microscopic examination. Annealing and Age hardening/Precipitation hardening were carried out the alloys. A universal tensile testing machine was used for the test during which each specimen was held against the two jaws of the machine and forces were applied gradually until the specimen fractured. Data were obtained from the process and tabulated for analyses. Electrical conductivity test was carried out using Wheatstone bridge (meter-bridge) method, where the specimen was the unknown resistance and was connected one side and a resistor of 2 ohms resistance on the other side. A galvanometer was used to get the balance point in meter along a constantan wire connected along a meter rule. The resistance of the test piece was calculated as shown below:

$$\frac{R_x}{R_n} = \frac{L_x}{L_n} \qquad 3$$

Where R_x is the resistance of the specimen, R_n is the known resistance (2 ohms in this case), L_x is the distance from of the balance point from the side of the unknown resistance and L_n is the distance of the balance point from side of the known resistance. Thickness of the specimen ranged from 0.089 to 0.095m, diameter was between 0.0012 and 0.0015m. The samples were prepared in cuboids form, some heat treated (Annealing and Hardening) and others left as cast. They were grinded to mirror like surface and then polished using aluminium oxide as the polishing reagent. The specimens for microscopic examination were etched after being polished by dipping in a freshly prepared solution of 2cc Hydrofluoric acid, 5cc Nitric acid and 100cc water solution as etching reagent for 15 to 60 seconds. After etching the specimens are mounted on the stage of the metallurgical microscope and adjusted to give a proper view of the structure and then it will be captured as it appeared on the monitor of the attached system.

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RESULTS AND DISCUSSIONS

The results of the tensile and electrical conductivity tests carried out on the specimens are hereby presented. The tensile test results are presented in Table 1. ANT, HNT and CNT are annealed, aged hardened and controlled (as-cast) samples respectively. Highest Modulus of Elasticity was recorded with age-hardened sample.

Table 1: Selected Tensile Properties of the Specimens

Specimen	U.T.S (MPa)	Strain, Ɛ	Young Modulus, E (GPa)
ANT	**571.56**	**0.06**	**158.77**
HNT	**594.54**	**0.07**	**170.67**
CNT	**603.28**	**0.08**	**143.64**

The stress-strain graphs from the tensile tests are shown in Figures 1-5:

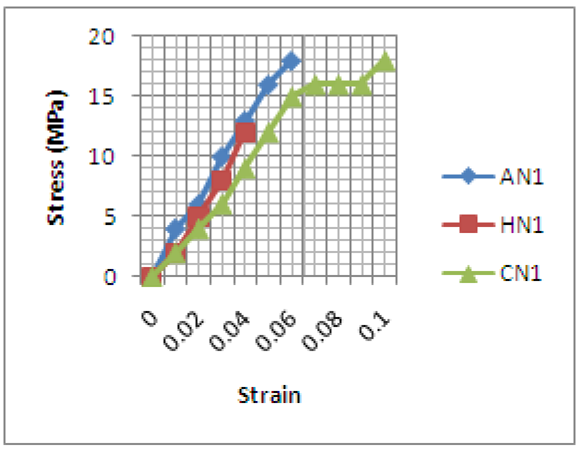

Fig 1: Stress-Strain Curve for Al-2%Ni Alloys

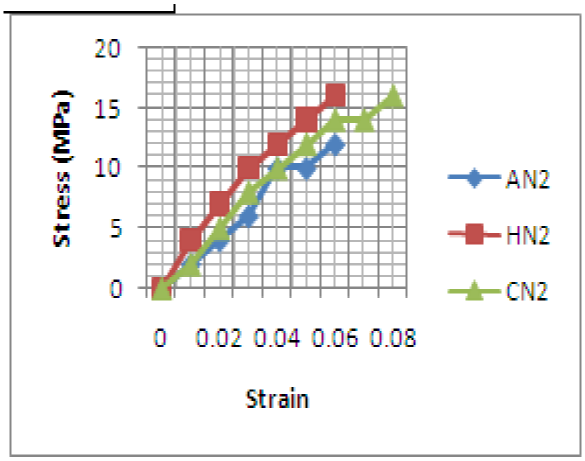

Fig 2: Stress-Strain Curve for Al-4%Ni Alloys

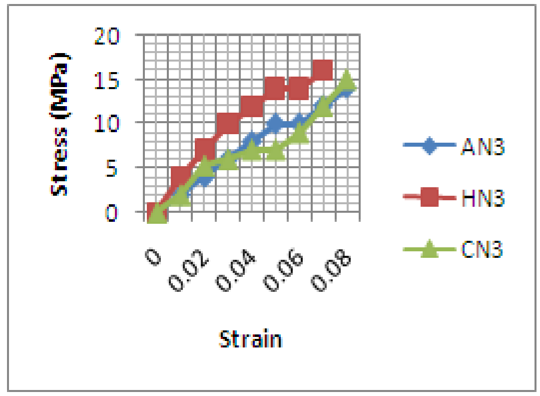

Fig 3: Stress-Strain Curve for Al-6%Ni Alloys

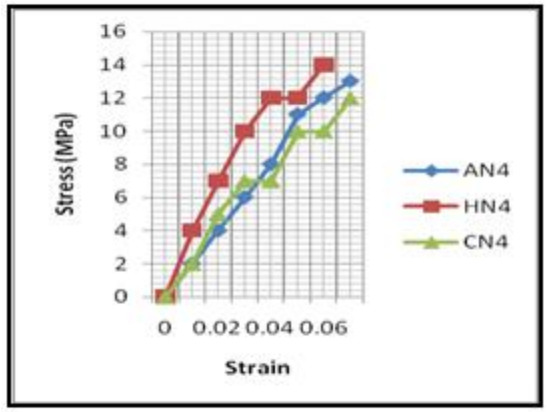

Fig 4: Stress-Strain Curve for Al-8%Ni

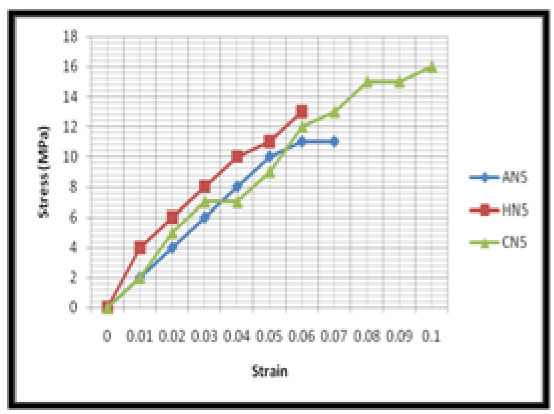

Fig 5: Stress-Strain Curve for Al-10%Ni Alloys

Figure 1, indicates that as-cast 2% Ni alloy was the toughest in the group, and in all the figures, annealing proved its worth as it reduced the hardness of the age-hardened alloys and rendered them more ductile.

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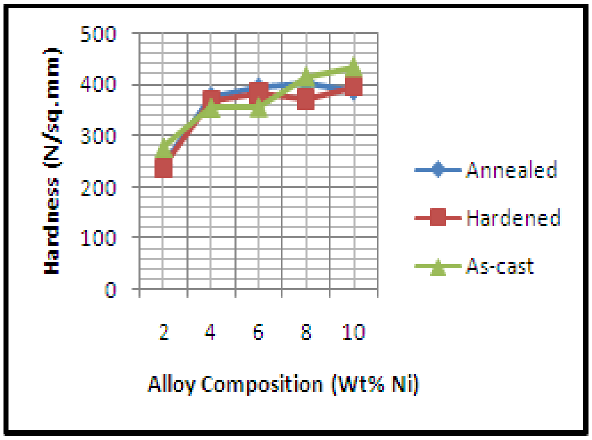

Fig 6: Hardness Values of Heat treated Al-Ni Alloys Specimens

Figure 6. shows the Brinell Hardness Number of the Al-Ni alloys, ranging from 2% to 10% Ni contents. It can be observed from the graph that Al-10%Ni as cast specimen has the highest HBN, which is 435, followed by 8%Ni hardened alloy with HBN of 416 and then 8%Ni annealed HBN of 403. The smallest value of the HBN is 238, for 2%Ni hardened specimen. The trend of the HBN shows that as cast alloy set have higher HBN over the annealed and Hardened alloy, with the exception of as cast 4%Ni, and 6%Ni.

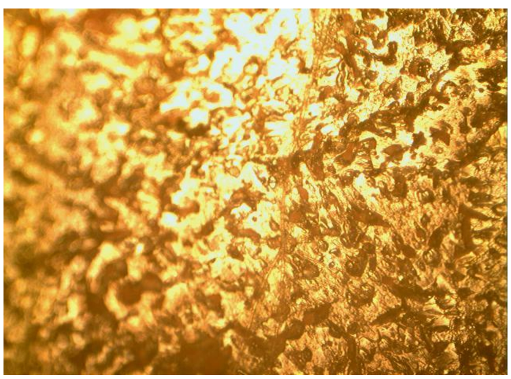

Plate 1: Annealed Al-2%Ni Alloy

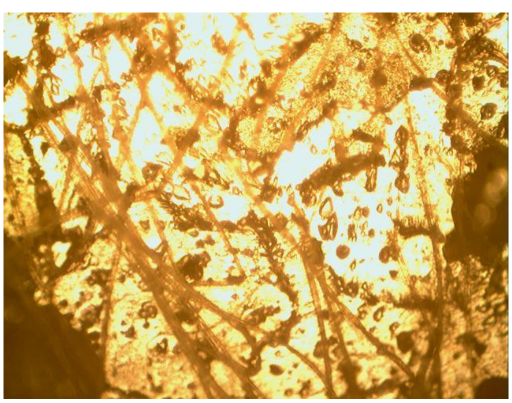

Plate 2: Annealed Al-4%Ni Alloy

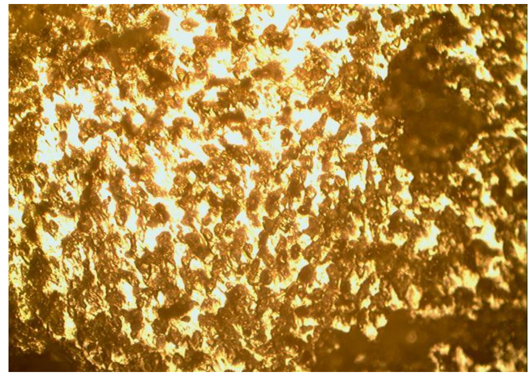

Plate 3: Annealed Al-6%Ni Alloy

In plate1 spheroidisation of precipitates of Ni can be seen throughout the matrix of Al, with slight white patches of primary Al around the top center of the matrix down midway, botryoidal structures intermixed with few of twinned grain and widmanstatten side plate can be seen on the graph. Plate2 can be seen having some patches of whitish primary phases of Al, spread within diffused precipitates of Ni, with dark patches of precipitates at bottom left and middle right of the matrix, nodular structure intermixed with fibrous structures of $NiAl_3$ dispersoids and continuous precipitates can be seen, Plate 3 is with spread precipitate of Ni spheroidised all over the matrix of Al with some few dark portion seen by top right, bottom right and left, nodular, acicular, and dendritic structures with dark segregates of Ni precipitates concentrated at the bottom right, left and near top right,

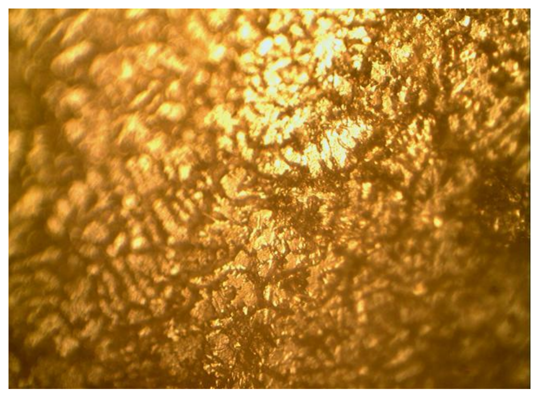

Plate 4: Al-2%Ni Hardened Alloy

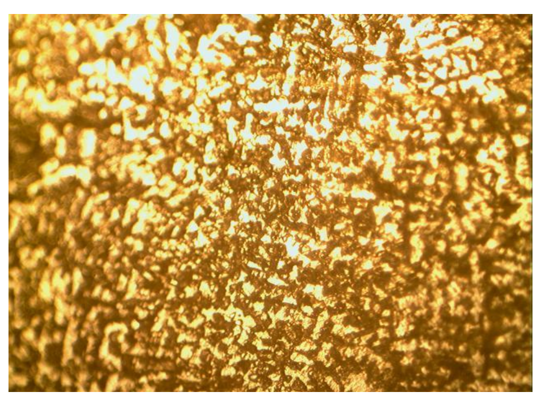

Plate 5: Al- 4%Ni Hardened Alloy

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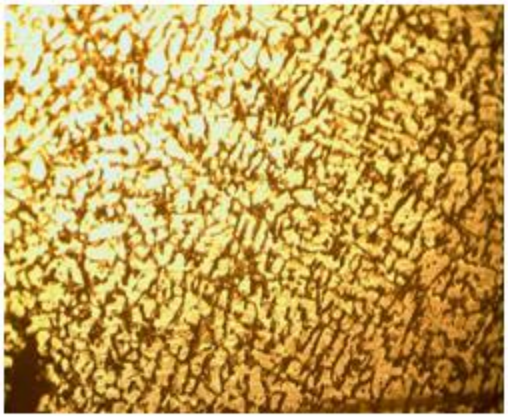

Plate 6: Al-6%Ni Hardened Alloy

In plate 4, the diffusion of the precipitates is much pronounced, with little patch of white patch of primary Al around the top center of the graph. Plate 5 shows patterns of mixed white primary phases and dark precipitates of Ni all over the matrix, the structure consist of small polygonal grains with patches of the eutectoid between them and interspersed with small globules of Ni and tiny acicular shapes can be seen, while plate6 is with lamellar precipitates of Ni throughout the Al-matrix, with a concentrated dark portion at the bottom left corner, there are recrystallized and twinned grains with straight twin lines and small grain size.

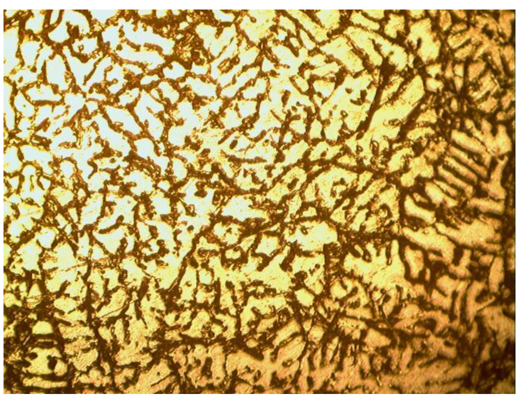

Plate 7: Al-2%Ni As Cast Alloy

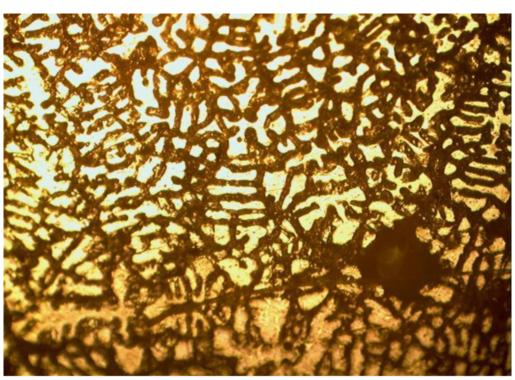

Plate 8: Al- 4%Ni As Cast Alloy

Plate 7 shows dendrites of the precipitated Ni all over the Al matrix. A cored grain with remnant of dendritic structure can be seen on the matrix, acicular and twinned structures can be seen on the right side of the graph. While plate 8 shows dendritic networks of precipitated Ni with a concentrated dark portion near bottom right of the graph. The micrograph is made up of acicular, dendritic, bonded and lenticular structure intermixed in the matrix of Al. While plate 9 has dendrites of primary phases of Al over the precipitates of Ni, dendritic, segregation, which brightened from right to the left intermixed with acicular structures.

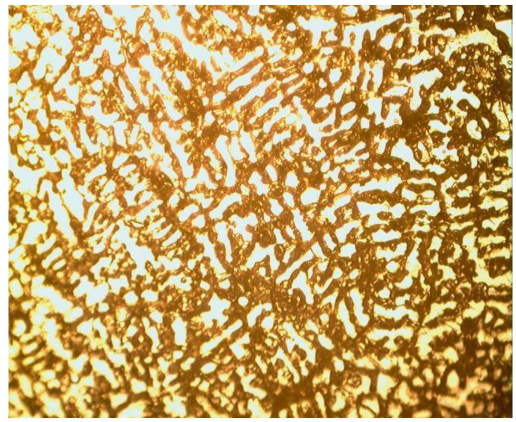

Plate 9: Al-6%Ni As Cast Alloy

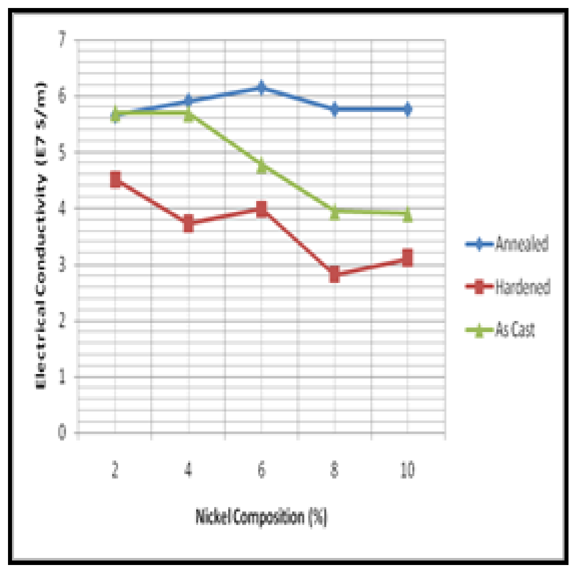

Fig. 4: Electrical Conductivity of Al-Ni Alloy Samples

It can be observed in Figure 4 that for all the compositions, annealed alloy samples have the highest electrical conductivity, while as-cast follow and hardened alloy samples have the lowest electrical conductivity. Though at 2%wt composition, as-cast alloy and annealed alloy almost have the same value, while at 4% the electrical conductivity almost equaled.

CONCLUSION

It is observed from the research that annealed alloys favour increase in electrical conductivity, whereas hardened alloys result in decrease conductivity, while untreated alloys have

moderate effect on the conductivity of the alloy. Ultimate tensile strength is favoured by hardening or leaving the alloy as cast, while annealing decrease the UTS of aluminium alloy. Al-4%Ni as cast alloy is the best alloy that can be adopted where high strength and electrical conductivity is a paramount requirement, such as in high tension electric cable especially in tropical region to prevent excessive sagging during hot season.

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